CAREER: New Materials in Condensed Matter Physics
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- Our lab concentrates on the development of new materials, focusing on those with exotic magnetic and electronic properties.
- One area of current interest is the behavior of spin gap compounds in high magnetic fields. Of particular interest is whether delocalized triplet excitations undergo Bose-Einstein Condensation at low temperatures.
- To experimentally address these issues requires the growth and measurement of high-quality single crystal samples. The following page describes the broad impact of the discovery and growth of these new materials.
- Figure 1 shows recent results for one particular spin gap material that we are investigating, $Sr_2Cu(BO_3)_2$, including data taken at the National High Magnetic Field Laboratory in Los Alamos National Laboratory.
- Currently very few spin gap compounds are known. Data like those shown in Figure 1 for a new member of this class of materials help us to understand their unusual properties.
- See cond-mat/0403334 for more details.

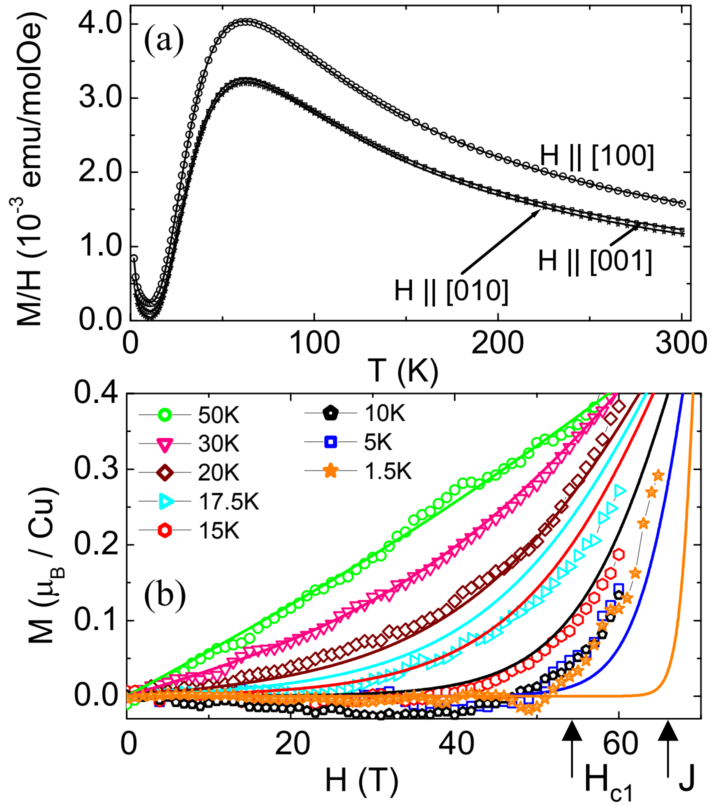

Fig. 1. (a) Low-field susceptibility of the spin gap compound $Sr_2Cu(BO_3)_2$. Fits to an isolated dimer model give an estimate of J ~ 100 K.

(b) High-field magnetization for the same compound. Solid lines show behavior of isolated dimers for J = 100 K. Weak inter-dimer coupling leads to a reduction of the critical field for triplet excitations such that H_{c1} < J.

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Magnetism has been with us since the discovery of lodestone, but many fundamental questions remain unanswered about the ways in which atomic magnetic moments can be arranged in solids and the ways in which they can interact with one another. Here we study a novel and intriguing material in which the magnetic moments are paired in to “dimers”. Interactions between these dimers results in exotic behavior that extends our understanding of magnetism in solids.

The magnetic materials that we are familiar with in everyday life possess some form of long range magnetic order – that is to say that below a critical temperature the magnetic moments are arranged on a regular lattice in an orderly fashion. Compounds that are composed of weakly interacting magnetic dimers are fundamentally different. As a consequence of their crystal structure, these dimer compounds have a non-magnetic (“singlet”) ground state, which has short range order but no long range order. Such dimer compounds are characterized by a “spin gap” – the smallest amount of energy that the magnetic degrees of freedom can absorb is not arbitrarily small but is a finite, and in some cases rather large, amount of energy. The properties of spin gap compounds are therefore very different to those of ordered magnets.

One particularly interesting feature of these compounds is that at low temperatures and in magnetic fields that are large compared with the spin gap, they undergo a phase transition to a complex magnetic state which *does* possess long range order. How this happens and the nature of the ordered state are currently poorly understood.

There are very few known examples of spin gap compounds, and so it is particularly exciting to discover and investigate a new member of this class of materials. Our experiments are helping us to understand more about how spin gap compounds respond to large magnetic fields and consequently more about the behavior of magnetism in solids.

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Broad impact of new materials synthesis:

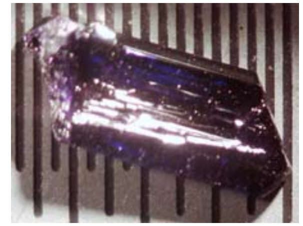
- The search for, and discovery of, complex new materials is an essential component for the continued health of Condensed Matter Physics in the US.
- Single crystals of these new materials are used for collaborative projects with US National Laboratories and universities.
- Students are trained in the design, discovery, growth and characterization of new materials.

Outreach activities:

- Participation, including graduate students from our group, in the QUEST program – providing research experience for financially challenged and under-represented students.
- Extensive undergraduate involvement in laboratory research.
- Continued involvement in undergraduate dorm events, elevating awareness of the role that materials research plays in both fundamental physics and technological applications.

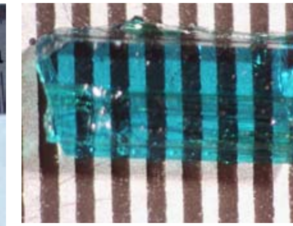
Educational activities:

- 2 grad students funded by this award
- 4 undergraduates funded by this award
- 2 students supported by an REU supplement

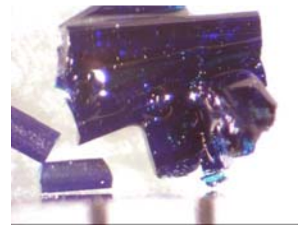


$Sr_2Cu(BO_3)_2$

$Ba_2Cu(BO_3)_2$

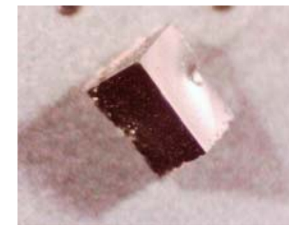


$BaCuB_2O_5$

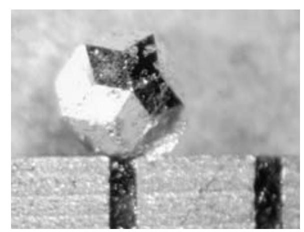


$SrCu_2(BO_3)_2$

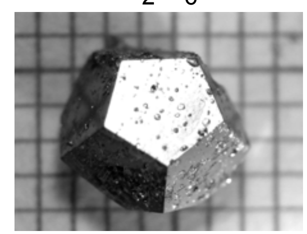
$BaCuSi_2O_6$



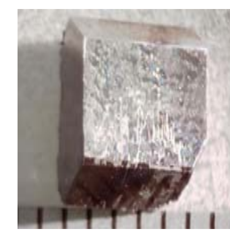
$BaPb_{1-x}Bi_xO_3$



R-Mg-Cd



Al-Pd-Re



$Tb_6Mo_4Al_{43}$

Fig. 2. Photographs of several complex oxides and intermetallics that we are studying as part of this CAREER award. In many cases these are new materials for which the magnetic and electronic properties are either unknown or poorly understood. These crystals are available for collaboration.

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